Effects of Exposures to Indoor Combustion Sources on Asthmatic Symptoms

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AIR & WASTE MANAGEMENT
A S S O C I A T I O N
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SINCE 1907

For Presentation at the
84th Annual Meeting & Exhibition
Vancouver, British Columbia
June 16 - 21, 1991

INTRODUCTION

Asthma is a chronic respiratory condition characterized by airway inflammation and intermittent episodes of bronchospasm that can be provoked by a variety of stimuli, including air pollution. Although there have been numerous controlled exposure investigations of the pulmonary effects of specific air pollutants on asthmatics[1-5], relatively few epidemiologic studies have examined relationships between asthmatic status and exposure to both indoor and outdoor sources of air pollution.[6-8] While indoor concentrations of some pollutants (e.g., ozone) may reflect outdoor levels,[9] others are strongly influenced by the presence of combustion sources, including gas stoves, fireplaces and woodstoves, and cigarette smoking.[10] Indoor combustion produces a complex mixture of chemicals, many of which are respiratory irritants that may affect people with asthma, including nitrogen dioxide, aldehydes, acids and particulate matter.[3,4,10-15] In this paper we report preliminary results of an analysis of relationships between indoor (and selected outdoor) exposures and respiratory symptoms in a population of adult asthmatics residing in the Denver, Colorado metropolitan area during the winter of 1987 to 1988.

DATA AND METHODS

Study Population

Study participants were recruited from patients attending the clinic of one co-author (J.S.). Diagnosis of asthma was made in each case by history and signs of airway obstruction on physical examination, confirmed by spirometric demonstration of obstruction reversible with a β-agonist bronchodilator (> 15% change in FEV_1). Asthmatic patients were identified by clinic staff and were recruited for participation either during an office visit or by telephone and postcard contact. Denver residents between ages 18 and 70 were eligible to participate in the study if they had asthma currently managed with medication. Individuals with any other chronic medical condition that would restrict their activity were excluded.

This panel of asthmatics was asked to record, on a daily basis for several months, information about symptoms, medication use, utilization of medical services, indoor exposures, and other variables described below. A panel study has several advantages over other investigative designs. First, it provides a large number of observations, increasing the degrees of freedom and the stability of any estimates. Second, problems of confounding, omitted variables, and exposure assessment, while always present, are substantially reduced since individuals serve as their own controls over time. Thus, the impact of factors that vary daily, such as air pollution, can be isolated while other factors are held constant. Third, the consideration of a given sample in one metropolitan location over time eliminates the potential for any intercity confounding.

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Health Measurements and Covariates

After giving informed consent, participants were required to fill out an intake questionnaire providing background data on demographics (age, sex, race, level of education, employment status, residential history), asthma severity and characteristic triggers and symptoms, medical history including medication use, smoking history, and previous environmental exposures. A diary instrument was designed to provide daily information on asthma symptoms, including the presence and severity on a scale of 0 to 4 (0-none, 1-mild, 2-moderate, 3-severe, 4-incapacitating) of cough, wheeze, shortness of breath, chest tightness, and sputum production, as well as physician and emergency room visits. In addition, information was obtained on the frequency of medication use, time spent outdoors, exercise intensity and location (i.e., indoors or outside), and potential indoor exposure to sources of respiratory irritants including gas stoves, fireplaces and woodstoves, environmental tobacco smoke, and occupational exposures. Participants were told that this was an investigation of environmental factors affecting asthma, but not that the principal variables of interest were air pollutants.

There were 330 intake questionnaires distributed (93 during office visits and 237 by mail) from November 15 to December 16, 1987. Of the initial group recruited, 256 returned the intake questionnaires. Study subjects were contacted by clinic staff intermittently throughout the study period (December 1987 through February 1988) to enhance compliance and continued participation. Ultimately, 207 patients submitted daily diaries, of which 182 contained complete information on indoor exposures. Table 1 displays the demographic characteristics and asthma severity for the latter group, who were predominantly white, female, employed and well educated, with an average age of approximately 46. The mean subjective asthma rating of moderate to severe is supported by the relatively large proportion of individuals taking daily oral theophylline and steroid preparations.

Exposure Measurement

Both outdoor and indoor air pollutants were considered as exposure measures. The ambient air pollutants available for the analysis were daily measures of sulfates, nitrates, PM2.5, nitric acid, hydrogen ion (H^+ -- an index of airborne acidity), and sulfur dioxide. Previous analysis of the data[16] indicated that, of the outdoor pollutants, H^+ was most strongly and consistently associated with respiratory symptoms and overall asthma status (though daily sulfate was also associated with one symptom -- shortness of breath). Therefore, H^+ was the sole outdoor pollutant used in this examination of the potential health effects of indoor air.

Daily measurements (9:00 a.m. to 4:00 p.m.) of H^+ were made at two monitors: one in downtown Denver, located about 2 miles from the clinic, and the other in the suburb of Arvada, located about 7 miles to the northwest. Because of problems in sample processing, the H^+ data were available only for half of the study period. Therefore, missing values

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were predicted using regression results with concurrent sulfate as the explanatory variable. With these substitutions, the daytime mean of H^+ was 8.15 nanoequivalents $(neq)/m^3$ or approximately 0.4 $\mu g/m^3$ measured as sulfuric acid, with the highest daily average of 44 neq/m^3. These levels are typical of urban areas.[17] Analysis of the two monitors recording H^+ indicated that the concentrations of airborne acidity were fairly evenly distributed; the daily between-site correlation of the readings was 0.88. Thus, the one downtown monitor was used to represent daily levels of H^+. Ozone concentrations, which frequently are highly correlated with sulfates and acids in the summer, were essentially at background levels through the winter in Denver (i.e., the maximum one-hour concentration was 0.042 ppm) and were not correlated with H^+ concentrations.

Data on indoor exposures were based on binary responses in the daily diary. No measurements of indoor concentrations were undertaken. The questions in the diary were:

Were you exposed to irritating smoke, dust or fumes today at work?
Were you exposed to cigarette smoke at home today?
Did you use a gas stove today?
Did you use a fireplace or wood stove today?

Table 2 provides descriptive statistics for the indoor and outdoor pollutants, meteorologic and health variables. The correlations between indoor exposures and outdoor pollution (H^+) are low (Table 3). All data from questionnaires, daily diaries, air quality and meteorologic monitoring were coded and edited in a SAS format for analysis.

Statistical Methods

In this analysis, three different health outcomes were used as dependent variables in logistic regressions: the probability of a respondent reporting on a given day a moderate (or worse) cough, moderate (or worse) shortness of breath, and severe cough. The latter measure was included in order to examine more closely the relationship of indoor exposures to serious symptoms. As a daily average, 17.2 percent (range: 8.7 to 33 percent) reported moderate or worse cough, and 17.8 (range: 9.1 to 28 percent) reported moderate or worse shortness of breath, and 3.8 percent reported severe cough (range: 0 to 10.3%) (Table 2).

We estimated effects on each health outcome using logistic regression models. Based on earlier analysis,[16] the other variables included in the regressions were outdoor air pollution (i.e., H^+), the number of the day of the survey (to correct for secular trends in reporting) and whether the individual reported a symptom on the previous day. Neither temperature nor humidity was related to health status and both were excluded from subsequent analysis. The impact of indoor air pollution was estimated by considering each source separately in a regression equation. The models were applied to men and women separately and combined.

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A different model was used to examine the impact of fireplaces and woodstoves. Exposure to emissions from this indoor source may be determined in part by the dependent variable in the regression; that is, the occurrence of a moderate or worse respiratory symptom may influence the decision to use a fireplace or woodstove. This potential simultaneity violates a fundamental assumption underlying regression analysis that the error term be independent of any of the explanatory variables. In order to address this potential problem, we used a simultaneous system of equations.[18] In this system, we first developed a regression equation to predict the use of a fireplace or woodstove. This predicted variable was then independent of the error term and, when substituted for the indicator variable (fireplace or woodstove use), generated an unbiased estimate.

RESULTS

Table 4 displays the results of the logistic regressions for the outcome of moderate or worse cough. The estimated coefficients for outdoor air pollution, measured as hydrogen ion, are presented with the four indoor air pollution sources, each considered separately in a regression. For the total sample, both the air pollution effect and all four indoor sources were associated with the probability of reporting a moderate or worse cough. Other significant influences on this dependent variable were the day of the survey and the occurrence of cough on the preceding day. For men, all four indoor sources were statistically significant, but outdoor H^+ was not. For women, outdoor air pollution was statistically associated with cough, while among the indoor sources only gas stove use was significant.

Table 5 displays a similar set of coefficients for the outcome of moderate or worse shortness of breath. Again, for the sample as a whole, both the outdoor air pollutant and all four indoor sources were statistically significant. In general, this result also held for both men and women. For severe cough in the entire sample as a whole, only the indoor sources were statistically significant (Table 6). For men, daily woodstove or fireplace use, exposure to occupational irritants and to residential tobacco smoke were all associated with the probability of severe cough. For women, gas stove and fireplace or woodstove use were significant.

Table 7 summarizes the increases in probability of moderate or worse cough attributable to indoor pollutant exposures. For example, use of a gas stove on a given day would correspond to 10.1% increase in the probability of moderate or severe cough in this study population.

DISCUSSION

The results of this preliminary analysis suggest that both outdoor air pollution and indoor sources of combustion play important roles in the exacerbation of cough and shortness of breath in a population of adult asthmatics. In a previous paper,[16] we showed that, among the measured outdoor air pollutants, ambient airborne acidity was most consistently related to the occurrence of these symptoms. This analysis focuses on the impact of several indoor sources: gas stoves.

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environmental tobacco smoke, fireplaces or woodstoves, and occupational exposures. For moderate or severe cough, men appear to be more susceptible to the effects of the indoor versus the outdoor pollutants, while the opposite is true for women. Further analysis is required to determine whether this disparity in gender-specific responses reflects differences in exposure time or intensity, asthma severity, or in the entire pattern of activities and joint exposures. It is possible, however, that the variation in the results for men and women may be attributable to the different sample sizes.

Shortness of breath in both sexes appears to be associated with ambient H^+ concentration and with all the indoor exposures. Episodes of severe cough are strongly associated with the use of a fireplace or woodstove in men and women, suggesting an irritant effect of woodsmoke. As for the relationship of the other indoor exposures to this outcome, gas stove use was an important factor for women, while occupational exposure and domestic environmental tobacco smoke were for men. It is reasonable to postulate that the myriad respiratory irritants produced by domestic combustion bear a direct causal relationship to the symptoms reported in this study. There may also be indirect interactions among the pollutants, e.g., increased bronchial reactivity from exposure to NO_2[3,4] in gas stove emissions may lower the threshold of response to substances in woodsmoke and environmental tobacco smoke. Such potential interactions are the subject of ongoing research.

Though it is widely recognized that people spend most of their time indoors, relatively few epidemiologic investigations have attempted to analyze the relative contributions of indoor and outdoor air pollution to the respiratory status of asthmatics.[6-8] In these studies, asthmatic symptoms were found to vary by season, with different combinations of outdoor and indoor (specifically, gas stoves and passive smoking) exposures significant at different times of the year. The results reported here are consistent with these other investigations, and also include quantitative estimates of the magnitude of the effects of indoor sources. In addition, we have found that ambient H^+ and use of a woodstove or fireplace significantly affect the probability of moderate or severe cough and shortness of breath. To our knowledge, this is the first empirical demonstration of this effect of woodsmoke on daily symptoms in adult asthmatics. Our findings are corroborated by other recent work indicating that ambient woodsmoke affects pulmonary function in asthmatic children[19] and that exposure to forest fire smoke is associated with increased emergency room visits for exacerbations of asthma.[14]

Previous studies have shown an effect of parental smoking on exacerbations of childhood asthma and, in a controlled setting, that some asthmatics are consistently sensitive to cigarette smoke[11,12]. This investigation documents a strong daily relationship between exposure to cigarette smoke and increased probabilities of clinically significant symptoms in free-living asthmatic adults. We have found a quantitatively similar relationship between gas stove usage and respiratory symptoms, which would not necessarily have been predicted from controlled studies of asthmatics exposed to low levels of NO_2 in environmental chambers.[3,4] It is possible that the effects we observed

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are a result of the relative severity of the clinical status of the study participants, or are driven by exposure to by-products of gas combustion other than NO_2, such as nitrous acid. At least one other series of studies has found an acute effect of gas stove usage on asthmatic pulmonary function, but the magnitude of the effect is difficult to assess.[6,8] With the caveat that these are preliminary results, the principal public health implication of our findings is that individuals with moderate to severe asthma should reduce to a minimum their exposure to residential sources of combustion, including fireplaces or woodstoves, gas stoves, and tobacco smoke.

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Table 1. Characteristics of Patient Population

Mean Age	45.6
% Male	34.0
Race (%)	
White	96.5
Black	1.5
Other	2.0
Education(%)	
College	62.0
High School	37.0
Less than High School	1.0
Employment status (%)	
Employed outside home	70.0
Homemaker	10.5
Retired	13.5
Other	6.0
Mean subjective asthma severity rating (0=none, 4=incapaciting)	1.7
% Daily Theophylline	58.0
% Daily oral steroids	18.9
% Current smokers	3.0

Table 2. Descriptive Statistics of Pollutant, Meteorologic
and Health Variables.

Variable	N (days)	Mean	Std. dev.	Min	Max
H+ (neq/m^3)	74	8.15	8.20	0.59	44.25
Minimum Temp (F)	105	17.71	11.97	-11.0	39.0
Moderate Cough (proportion/day)	74	.172	.049	.087	.33
Severe Cough	74	.038	.019	.000	.103
Moderate Shortness of Breath	74	.178	.034	.091	.280

Table 3.   Correlation Coefficients for Exposure to Indoor
Sources, Ambient H+ and Temperature.

	H+	Gas	Occup.	ETS	Fire
Gas	.00				
Occup.	.01	-.00			
ETS	.01	.04	.03		
Fire	.03	.09	-.02	.03	
Minimum Temp.	-.33	-.01	-.00	-.03	-.10

Note: H+ = outdoor hydrogen ion concentration; Gas
= gas stove; Occup. = occupational exposure; ETS =
environmental tobacco smoke; Fire = fireplace or
woodstove.

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Table 4. Logistic Regressions Coefficients Relating Indoor and Outdoor Exposures to Moderate or Severe Cough.

Exposure	All	Men Only	Women Only
Log(H+)	.0892[a]	.0035	.1278[a]
Gas Stove	.7314[a]	.8793[a]	.6289[a]
Log (H+)	.0699[b]	-.0275	.1109[a]
Woodstove or Fireplace	1.0571[a]	3.3770[a]	.6315
Log (H+)	.0873[a]	.0097	.1247[a]
Passive Smoke	.1943[b]	.4774[a]	.0336
Log (H+)	.0784[a]	.0047	.1132[a]
Occupational	.1342[c]	.6272[a]	-.1371

$a = p < .01$; $b = p < .05$; $c = p < .10$

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Table 5. Logistic Regression Coefficients Relating Indoor and Outdoor Exposures to Moderate or Severe Shortness of Breath.

Exposure	All	Men Only	Women Only
Log (H$^+$)	.0967[a]	.1018[b]	.0962[a]
Gas Stove	.6362[a]	.4343[a]	.7836[a]
Log (H$^+$)	.0734[a]	.0613	.0788[b]
Woodstove or Fireplace	2.4293[a]	4.6984[a]	1.0416[a]
Log (H$^+$)	.0957[a]	.1110[b]	.0936[a]
Passive Smoke	.6145[a]	1.1365[a]	.2082[c]
Log (H$^+$)	.0892[a]	.1004[b]	.0864[a]
Occupational	.3185[a]	.7549[a]	.0486[a]

a = < .01; b = p < .05; c = p < .10

Table 6. Logistic Regression Coefficients Relating Indoor and Outdoor Exposures to Severe Cough.

Exposure	All	Men Only	Women Only
Log (H+)	.0278	.0069	.0343
Gas Stove	.7732[a]	.3805	1.0607[a]
Log (H+)	.0236	-.0308	.0333
Woodstove or Fireplace	1.7571[b]	3.8546[a]	1.8750[a]
Log (H+)	.0264	.0186	.0327
Passive Smoke	.4363[a]	1.0572[a]	-.0415
Log (H+)	.0251	.0037	.0341
Occupational	.5233[a]	1.2964[a]	.0910

$a = p < .01$; $b = p < .05$; $c = p < .10$

Table 7. Estimated Magnitude of Effect of Indoor Sources on Moderate or Severe Cough.

	Estimated Increase in Symptom Probability		
Effect of Daily Exposure From:	All	Men	Women
Gas Stove	.104	.125	.090
Woodstove or Fireplace	.151	.481	NS
Passive Smoke	.028	.068	NS
Occupation	.019	.089	NS

NS = Estimated effect not significantly different from zero.

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